A STUDY OF NUCLEAR POWER PLANT CONSTRUCTION IN THE UNITED STATES

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BY

ROBERT P. WALDEN

A REPORT PRESENTED TO THE GRADUATE COMMITTEE OF THE DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING

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ABSTRACT

Construction of nuclear power plants in the United States has experienced a serious decline during the last decade and has virtually stopped since 1988. However, the demand for energy in this country continues to grow at an alarming rate. The United States possesses the technology and capital to produce more nuclear-generated electricity. If the need is there and the technology and money are available to meet that need, then why has this specialized industry experienced such a dramatic decline?

The answer to this question is not a simple one. Two of the primary reasons for the decline in nuclear power plant construction are: the regulatory demands placed on the industry by the Federal government, and the public's perception of safety regarding the nuclear power industry.

The construction of nuclear power plants is obviously a complex and capital-intensive undertaking. The history of nuclear power plant construction in the United States has been one of enormous cost and schedule overruns. Proponents of nuclear power, within the government and industry, are attempting to pass new legislation which will require a one-step licensing procedure and promote a standard design for all new nuclear plants. The one-step licensing procedure and the standard design are both major

incentives that may help rejuvenate this specialized industry.

The purpose of this study is to examine the reasons for the decline in nuclear power plant construction in the United States with emphasis on government involvement and public opinion.

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CHAPTER 1

INTRODUCTION

Background

In 1990, there were 112 nuclear reactor units with operating permits in the United States. However, the number of units with construction permits has steadily declined from 91 in 1979 to four in 1990. Today, there are currently no new units planned for construction (18:5).

"The United States Department of Energy (DOE) says the country will have to raise its present generating capacity of 700 billion watts another 250 billion watts by 2010" (6:56). This increase is equivalent to the generating capacity of 250 nuclear power units. The DOE has also estimated that the United States will need an additional 1,250 billion watts of generating capacity by the year 2030. Further compounding the need is the realization that many existing nuclear plants, which were designed for forty years, will have their operating licenses removed during the coming decade (6:56).

As our energy needs increase and foreign sources of oil become less reliable the Federal government is providing increased support for new legislation that would ease the current regulatory climate governing nuclear

power plant design, construction, and operation. The proposed legislation calls for a one-step licensing process to be completed prior to commencing construction. Current regulations require one permit to be issued for construction and one permit to be issued for operation of the plant. This two-step procedure also requires a public hearing before each of the licenses is issued (9:1).

The Bush Administration has also requested that key suppliers of nuclear plants build them to a standard design. The advantages of standardization are obviously: cost efficiency, better maintainability, and ease of repair. A likely candidate for standard design is the modular high-temperature gas cooled reactor (MHTGR) (6:55).

Problem Statement

The number of nuclear power plants under construction in the United States peaked in 1979 and since that time nuclear power plant construction has stopped. Utility companies ordered their last new power plant in 1978 (6:54). Licensing and regulation by the Federal government has become such an extensive process that the most recent units placed into operation in 1989 and 1990 had an average construction time of approximately 17 years (18:12).

Nuclear accidents at Three Mile Island and Chernobyl have created a strong "rallying cry" for opponents of nuclear power and have had tremendous negative impact on

the growth of the industry. Public opinion, cost overruns, and legislative overkill have forced utility companies in the United States to abandon 120 nuclear plants since 1974. Amazingly, more nuclear plants have been abandoned than are currently in operation. The total costs of abandonment are estimated in the hundreds of billions of dollars (6:56).

Nuclear power plant construction has historically experienced enormous cost and schedule overruns. Some of the problems with cost and schedule can be attributed to the constantly changing government regulations regarding siting, design, and licensing. However, other factors have also influenced cost and schedule negatively. Among these factors are: overall poor construction management, quality control and quality assurance problems, and poor public relations by the utility companies and the industry.

Report Objective

This paper will examine the reasons for decline in nuclear power plant construction in the United States with major emphasis on government involvement and the public's perception of safety in the industry. The current status of construction and the possible reactivation of abandoned plants will also be reviewed. From a construction management viewpoint: safety, quality assurance and control, contracting systems, cost control, and scheduling

will be studied to provide insight into how these factors contributed to the current state of the industry.

Current issues regarding future energy needs, radioactive waste disposal, design standardization, and legislative reform will be discussed relative to their role in possible rejuvenation of the nuclear power plant construction industry.

CHAPTER 2

LICENSING AND LEGISLATIVE REFORM

"The regulatory process affects the industry by lengthening the time between planning a new generating facility and placing it in operation, by retroactive changes in plant design arising from the unique surveillance responsibility of the Nuclear Regulatory Commission, and by providing a special forum for public opposition to nuclear plants" (12:278).

The above statement indicates that one of the critical areas affecting construction of nuclear power plants is licensing and government regulations covering the construction and operation of the power plants. Proponents of nuclear power claim that the licensing process and the current regulations are key areas that must be reformed in order for the industry to experience revitalization.

The licensing procedures and regulations governing the design, construction, and operation of nuclear power plants is contained in Title 10, Chapter 50 of the United States Code of Federal Regulations. Prior to starting construction on a nuclear project the Nuclear Regulatory Commission must issue a construction permit (17:532).

The licensing process for construction contains four major steps. The first step is the filing and acceptance of the application by the NRC. This document usually consists of fifteen or more volumes of material and is known as the Preliminary Safety Analysis Report (PSAR). The PSAR is prepared and submitted by the utility company or owner and shows in detail the design assumptions and limitations of the proposed plant. Along with the PSAR the owner files an Environmental Report (ER). The time required to prepare these two documents can take up to two years (4:352).

The second stage in obtaining the construction permit consists of a review of the PSAR and ER by the NRC. This review process takes approximately eighteen months. The NRC staff reviews safety, environmental safeguards, and antitrust issues. The third step is a more comprehensive safety review by the Advisory Committee on Reactor Safety (ACRS). The ACRS is commissioned by the NRC, but is an independent agency. This review is required by federal statute (4:352).

The last step in the construction licensing process is a mandatory public hearing by the Atomic Safety and Licensing Board (ASLB). This board is composed of three members - a chairman and two technical advisors, all with expertise in environmental and nuclear technology. This portion of the licensing procedure varies drastically in duration depending upon those who are interested in seeing

the plant built or those who are not interested in seeing the plant built. These public hearings have varied in length from one day to three years (4:352).

The time involved in obtaining a construction permit is a great source of frustration to the nuclear industry. This chapter will focus on how the licensing process has affected the industry and the push for legislative reform that is currently ongoing to alleviate the problem.

The existing licensing process requires two public hearings and two separate licenses - one prior to granting the utility a construction permit and another before the plant can begin operation. This dual licensing process, which allows the public to intervene at critical steps, has caused many of the cost and schedule overruns associated with the construction of nuclear power plants. For example, the second round of public hearings (required before the issuance of an operating license) kept the Seabrook Nuclear Power Station in New Hampshire idle for three years. This delay cost the owner over $1 billion in interest and other expenses (6:61).

As can be seen by this illustration, the nuclear licensing process is not only a political issue, but also a serious economic issue that will directly affect how much America pays for electricity for the first half of the 21st century. A recent analysis by the United States Council on Energy Awareness (USCEA) compared the cost of electricity from four electric generating options -

nuclear, coal, gas, and oil. The analysis showed that the nuclear plant could produce electricity for 4.3 cents/kilowatt hour (kwh). This compares to 4.8 cents/kwh for the coal plant, 6.1 cents/kwh for the gas fired plant, and 8.1 cents/kwh for the oil fired plant (11:42).

The results of this analysis were based on the key assumption that new advanced nuclear energy plants would be built under stable regulatory conditions. Stable regulatory conditions means that standardized designs will be utilized and that all regulatory issues (including siting, design, and emergency planning) will be settled before construction starts and not afterwards. The USCEA analysis also assumed that plants built to the Nuclear Regulatory Commission's rigid specifications will be allowed to start up upon completion of construction, and will not be subject to lengthy public hearings which cause costly delays (11:42).

The results showing nuclear power as the most economical means of electrical generation may be hard to believe considering the costs of recently completed plants. (To provide a common ground of measurement, nuclear power plant construction costs are measured in dollars per kilowatt (kwe) of peaktime generating capacity.) The first plants completed in 1968 averaged $161/kwe. Five units completed in 1988 averaged over $3000/kwe. This amounts to an 1800% increase in a twenty year period. By comparison the consumer price index (the

Federal government's measure of annual inflation) only increased by about 300% in the same period. There is no doubt that the demanding regulations and the lengthy licensing process have had a major effect on the cost increases (18:11).

The main concern of utility companies is not the regulations themselves but the fact that the process lacks stability and predictability. When planning for capital investments of the magnitude of a nuclear power plant it becomes important to be able to accurately estimate all the costs associated with the project. This has been almost impossible because of constantly changing regulations and public involvement in the licensing procedure. The two-step licensing procedure that is currently used requires utilities to take a huge financial risk on a design that is not completed and finally approved until the plant is constructed. The lack of a standardized design has also contributed to some of the differences in the licensing procedure (19:2).

The costs for constructing a nuclear power plant have escalated rapidly during the last two decades, at a much higher rate than inflation. This escalation has been partly due to changes and additions to plant designs required by regulations for improved safety or environmental protection. Because of the uncertainty of these changes, which often result in completed costs orders of magnitude higher than the original estimate,

utility companies have been reluctant to plan for and fund any new reactors (12:263).

Under the existing law construction begins before the plant design is completed. Critical decisions on approval of the plant design are often made after construction has begun. This process is extremely inefficient, increases the overall costs dramatically, and has forced many projects to be abandoned after owner's have sunk millions and sometimes billions of dollars into construction (19:2).

Part of the increased costs related to regulation can be associated with the contractor and owner attempting to cover risks that are uninsurable. As previously stated, regulatory changes frequently cause changes in design, which result in rework and delays or shutdowns in the construction schedule. Also related to risk management are the costs associated with risk due to delays in licensing that may occur once construction has been completed. The costs for these risks are included as contingencies in the construction schedule of prices and this is standard in the industry (12:272).

By comparison, fossil fuel plants usually require eight to ten years from the start of planning to completion of construction, nuclear plants are now averaging over seventeen years. A large portion of this additional time is because of the extensive reviews required for nuclear plants prior to construction. This

extra time costs money and increases the uncertainty of meeting the original target cost of construction. The nuclear industry would very much like to shorten the time period used by the licensing process. Since the industry is regulated by law, this will only be accomplished through legislative reform (12:278).

As can be expected in a democratic country, the public has great influence over matters affecting public safety. Congress is certainly attuned to this and has created laws and a bureaucratic agency to regulate all facets of the nuclear power industry. The regulations themselves have been proven capable of being met. The actual regulations have not caused the decline experienced by the industry. The problem has been the numerous changes in regulations that are imposed on the owner, designer, construction-manager, and contractors during the construction phase. These changes are much more expensive to implement during the construction phase then they would have been during design. Each change in regulations increases the opportunity for further legal and administrative interventions during the life of the project. This is especially true during the public hearing held before the operating license is obtained (12:278).

Another area of frustration is the ability to the public to intervene during the licensing process. "Interventions have been used to increase opposition to

nuclear power, and in some cases, have forced postponement or cancellation of nuclear power plants, either by generating resistance in the region affected, or by delays that bring the economics of the plant into question" (12:278). The same individuals questioning the economics of a particular plant during a public hearing often do not realize that they are directly contributing to the cost inefficiencies by delaying either the construction or operation of the plant.

While it has been good from a safety standpoint to have a strong regulatory environment surrounding this industry, from an economic standpoint it has been a major liability. However, a competent and independent regulatory agency is also necessary to ensure any resemblance of public acceptance of nuclear power. Public opinion and acceptance of this industry must be changed drastically from what currently exists if nuclear power is to make a comeback (12:279).

Legislative Reform

In February 1991, President Bush published his new energy policy. Included in this policy is a proposal to speed up the procedure for licensing the next generation of nuclear plants. This "streamlining" process places limits on the public's ability to comment on new plants and the ability of state utility commissions to regulate them. The proposed legislation also limits a state's

ability to comment on the location of disposal sites for radioactive wastes (13:2G).

As of April 1991, this legislation had won approval from the Senate Energy Committee. A clear majority of the committee members endorsed the new legislation. The key points of the new legislation are: a one step licensing procedure to occur before construction begins, twenty year renewals on operating licenses for existing plants, and commitment of government funds to conduct research for developing modern, standardized plant designs (9:1).

Because of recent events in the Persian Gulf and increased concern over the emission of carbon dioxide into the atmosphere, the current administration, the utility companies, and the scientific community are taking a second look at the many advantages of nuclear power as an energy resource for this country during the next century.

Utility companies are well aware of the capabilities of nuclear power, but are reluctant to expend further resources until the Federal government stabilizes the regulatory process so that costs and schedules can be planned within a reasonable probability of being on target upon completion.

The history of construction in this industry has shown that the probability of being on target for cost and schedule has been much less than reasonable. The main reason for this is the current licensing process. The President and some members of Congress have recognized

this and are attempting to correct the problem through legislative reform. If the new legislation is passed it will certainly provide the prime impetus in revitalizing the industry.

The USCEA analysis, previously mentioned in this chapter, "shows that with licensing reform and a stable regulatory climate, nuclear plants can be one of the least cost ways to meet future electricity needs. As a result, consumers of electricity would be the main beneficiaries of a more stable regulatory and licensing system for future nuclear plants" (11:42).

As with most economic issues in the United States, costs will drive the market. If the licensing system does improve and costs can be reasonably predicted and controlled on nuclear power plants, then utility companies will once again start planning and constructing more of them.

When asked about the need for nuclear power during the coming decade, Mr. Alan Stoga, a member of the Board of Directors of Kissinger and Associates (a geopolitical and economic consulting firm), had these comments:

> We need to get away from our dependence, not just on foreign oil, but on oil. To the extent we can replace oil with non-oil sources, we ought to do so. There, I think, is where we have to re-examine the role nuclear power plays in our energy mix. I find it criminal--and that really is the best word--that we have abandoned nuclear power for all practical purposes.
>
> The federal and state governments should be in the business, not of preventing nuclear power at any cost, but of providing the regulatory,

the safety, the economic framework in which sensible investment decisions can be made. They have not been. Rather, they have been crusaders with a mission to discourage, and prevent, additions of nuclear power to the nation's energy resource stock. We need to create a regulatory process that offers the opportunity to license new facilities. We need to create a system where the chances of approval at the end of the day justify the massive investment at the start of the day, and that really is the role of the federal government (11:49).

CHAPTER 3

STANDARDIZATION

With few exceptions, the 112 nuclear reactors built in the United States have been custom-designed and custom-built. Almost all of the 112 licensed plants are one of a kind. Building one of a kind plants on a design-as-you-build basis has resulted in both safety problems and escalating construction costs. These two issues have resulted in a lack of investor and public confidence in nuclear power (19:1).

The United States House of Representatives' Committee on Energy and Power held hearings in May of 1988 to discuss the issue of nuclear power plant standardization. The committee hearings involved many people from the industry and the scientific community. The findings from the hearings indicated that standardization was a "good" idea and that Congress should enact legislation to encourage standardization in the industry (19:1).

There is enormous financial risk involved on the part of the utility companies and owners with the current two-step licensing procedure. The use of standardized designs would reduce that risk and help revitalize the use of nuclear power as a profitable electricity-generating option. The custom design approach has led to numerous

reactors of great variability and diversity. The variability has created differences in the licensing of nuclear power plants and difficulties in transferring experience and materials from one plant to another (19:2).

Standard designs can reduce the cost of new plants and improve their safety. This is realized through improvements in training, operation, and maintenance that can be readily shared between facilities. Also, standardized designs provide additional assurance that all major elements of a nuclear power plant are produced to exacting requirements and that these requirements have been subject to a complete public review process. Standardization allows for a more efficient and expeditious review process and thorough understanding of the designs by the NRC. Each of these effects of standardization relate to reduced overall costs (19:2).

Newly introduced legislation in the House of Representatives calls for the pre-approval of standardized design and a combined construction permit-operating license hearing for the design. Unlike existing legislation, plant construction would not begin until after the design has been fully reviewed and approved. This approach will enhance safety, decrease the cost of nuclear power plant construction, and hopefully, give the industry a much needed boost in construction starts (19:2).

Regulation is one of many reasons why nuclear power plant construction has experienced zero growth in recent years. Standardization plays a key role in regulatory reform. However, whether or not there is regulatory reform, utility companies, out of economic necessity, must look at standardization as a means of reducing spiraling construction costs (19:3).

Standardization is not the only answer to revitalizing the industry. Problems with public acceptance and investor concerns must also be overcome. These two areas can be relieved by the use of standardized designs because this will result in lower costs and safer plants. However, standardization through regulatory changes must be done carefully so as not to agitate these two groups any more than they already have been (19:3).

If standardized designs are going to be used, which design should be chosen? There are a number of good designs that have been built and operated during the past thirty years. However, they have all experienced problems. It would be too easy with the existing designs for somebody to find something that should be built better, or to require some backfitting. Therefore, a look at alternatives in new technology should be done to pick the best design or group of designs from which to chose (19:4).

There are currently two design alternatives that are available that provide for the most advantages in terms of

standardization. They are: the advanced light water reactor (which is basically an improvement over most of the current reactors) and the modular high temperature gas-cooled reactor (MHTGR) (19:4).

The advanced light water reactors are in the design stage now. The designs are being accomplished by Westinghouse, General Electric, and Combustion Engineering. The first two companies are cooperating with Japanese firms in their designs. The new design is significantly safer, from an operating standpoint, than existing plants. The risk factor for a catastrophic accident occurring has been lowered by a factor of ten with this design. This is a significant accomplishment (19:4).

These advanced reactors will be designed to be more easily operated and therefore, less susceptible to disruptions and shutdowns. This, in turn, results in a more stabilizing licensing environment, meaning the license should be more easily obtainable upon completion of construction, because there are fewer opportunities for things to go wrong. The ease of licensing efforts means less risks for the owner, less delay time between completion of construction and operation, and more importantly, a lower and more stable overall cost (19:4).

These designs will be available for construction in a few years. In all probability the Japanese will construct the first one, so the United States will have an

"experiment" to analyze if we chose this option. It is not clear what the public opinion will be since this design is only a modernization of the most prevalent design in operation today (19:5).

The modular high-temperature gas-cooled reactor uses helium gas as a heat transport medium rather than water. This design centers on loading modular fuel units, capable of withstanding extremely high temperatures (3300 degrees Fahrenheit), into reactor vessels small enough that they do not hold enough fuel to cause a "meltdown" of the reactor core if all the helium gas escaped. The helium transports the heat from the fission process to a gas turbine, which provides the motion for the electric generator to produce electricity (6:58).

This particular design has been the only one to receive support from the Union of Concerned Scientists, which is a group of scientists, researchers, and academicians that has traditionally opposed the use of nuclear power in any form. Proponents of the design state that it is "idiot-proof" and "inherently-safe," mainly because it relies on the laws of physics and not human intervention to prevent a major accident. One significant drawback to this design is the lack of a containment vessel which makes it vulnerable to terrorist attack and sabotage. From a public perception standpoint, if a reactor which is advertised as inherently safe ever experiences a major accident, public confidence in that

technology might never recover, especially in the United States (6:58).

The French have proven that standardized designs are less costly and can be built quicker. France generates 75% of its electricity from nuclear power, more than any other country in the world. They have used a standardized reactor since the mid-1970's. The average construction time has been six to eight years. This compares to a current average time of seventeen years in this country. France's nuclear engineers and operators can work on any of the country's fifty-five nuclear plants. The cost efficiency and safety value of standardization is self-evident (6:55).

The Bush Administration has recognized their importance and is supporting the use of standardized designs, both financially and politically. The United States Department of Energy (DOE) has invested more than $160 million during the past five years to assist in developing a new generation of advanced reactors with standardized designs. General Electric, Westinghouse, and other participants in the program have also invested over $70 million for this effort. The administration wants at least four designs ready for utilities to choose from by 1995 (6:61).

Currently, the Federal Regulations regarding nuclear power plant construction and operation allow for the following standardization options: duplicate design,

replicate design, reference design, and license to manufacture (17:526).

Duplicate Design allows for a single review of the construction license application for two or more plants. The plants have the same design and will be constructed in a specified time frame at different sites. The only difference in design allowed are those related to site adaptability. One set of drawings is prepared and all equipment is procured at the same time. Therefore, each unit that is built has the same make and model of all major items (10:471).

Replicate Design is nearly an exact replication of a previously established design constructed at a later time at the same site or a different site under separate license applications. Equipment is procured to the same performance specification as used in the original design, but may have some variations because of different manufacturers (10:471).

Reference Design allows the design of an entire plant, or major systems of the plant, to be reviewed with the intent of being standardized for use in subsequent plant applications. The second and subsequent applications would merely reference the first (10:471).

The license to manufacture concept provides for a licensing review of several facilities that are to be constructed at a location different from where the plant will operate. The licensing review and hearings are

limited to site-related questions. This idea applies primarily to barge mounted off-shore power plants (10:471).

All of the above options are available and provide for some degree of standardization. They all still require two-step licensing. The intent of the legislative reform currently in progress is to use the reference design option with a one step licensing procedure. This concept hinges on finding a design flexible enough to be adapted for sites almost anywhere in the United States.

The sound economic sense of using nuclear power plants that are uniformly standardized, built on a reliable schedule with a firm price, as part of this country's energy policy has been clearly demonstrated. Project managers overseas and in the United States have constructed power plants in six years or less.

The construction methodology and technology for building the six year plant exists, however the industry-wide commitment to make it happen consistently in the United States is severely lacking. The utility companies and the government are showing a greater awareness toward increasing nuclear power generating capacity. To accomplish this, everyone involved in the industry--the utility companies, the manufacturers, Federal and state regulators, the financial community, and the politicians--must form a long term partnership based on shared risk and shared rewards. This partnership would be based on the

fundamental concept that a nuclear power plant will be constructed in six years with a firm fixed price (2:646).

For the six year process to work the partners must agree on: the need for additional power capacity, extensive pre-construction design and planning, financial backing and risk sharing, firm price bidding with financial incentives based on performance, reduction of regulatory uncertainties, streamlining of the licensing process, and early identification and resolution of potential risk issues (2:647).

The first and most important step in making this process work is legislative reform requiring only one-step licensing and the use of standardized designs. The use of standardized designs will reduce costs, increase safety, and provide the public with the needed assurance that nuclear power is both safe and economical.

CHAPTER 4

THE PUBLIC'S PERCEPTION

"Nuclear power. The words conjure first the hellish explosion at Chernobyl that spewed a radioactive cloud across the Ukraine and Europe five years ago, poisoning crops, spawning bizarre mutant livestock, killing dozens of people and exposing millions more to dangerous fallout. Then the words summon up Three Mile Island and the threat of a meltdown that spread panic across Pennsylvania's rolling countryside seven years earlier. From these grew the alarming television programs, the doomsday books, and the terrifying movies. Could any technology survive all that? It seemed this one couldn't." This is part of the opening paragraph for the cover story of the April 29, 1991, issue of Time magazine entitled "Time to Choose" (6:56).

In this paragraph a gloomy and dreadful picture is painted concerning nuclear power. The two major accidents that occurred, one in the Soviet Union and the other in the United States, have had an overwhelming effect on the nuclear power industry. Opponents of nuclear power have used these two events to their advantage. Opposition to nuclear power is well-organized. Every opportunity is taken by the opposition to inform the public about the

negative aspects of nuclear power. Conversely, the nuclear power proponents, including the industry, do not have an organized public relations campaign. Consequently, the majority of public opinion has been against any further development of nuclear power.

This chapter will attempt to review three key issues that relate to the public's perception about nuclear power. These issues are: safety, effects on the environment, and cost. Because of their ability to intervene during the licensing hearing, winning the public's opinion in favor of the growth of nuclear power is crucial to nuclear power plant construction. Public challenges made during licensing phases are one of the key causes of cost and schedule overruns.

The nuclear power industry must convince the public that the new plants that are built will be safe and have fewer problems. This will be a crucial challenge, for without public support this industry will surely fail. A Time/CNN poll conducted in April, 1991, showed that 32% of 1,000 adults surveyed strongly opposed building more nuclear plants in the United States, 18% were strongly in favor of building more (6:55). Conversely, a New York Times/CBS News opinion survey conducted in June, 1991, found that 41% of the 1424 adults polled were in favor of building more nuclear power plants. However, this percentage is down from the 46% who said they would approve in April, 1979, one month after the Three Mile

Island accident, and significantly lower than the 69% who said they would approve in July, 1979 (20:3A).

The Time/CNN poll of April, 1991, also asked which energy source the United States should rely on most to meet increased energy needs in the next decade. Surprisingly, 40% of the respondents chose nuclear power, 25% chose oil, and 22% named coal. The contradiction of not wanting to build more nuclear plants, but choosing it as a viable energy resource is probably due to the "not in my backyard" syndrome. Many people want nuclear power as long as it is generated somewhere else. 60% of those asked stated that a new nuclear power plant in their community would be unacceptable, while 34% said it would be acceptable (6:56).

The public does not want nuclear power in their backyards because of the perception that nuclear plants are unsafe. Public concern about nuclear power safety has centered on four key issues: the safety of routine operation of the nuclear fuel cycle and of reactors, the possibility and effects of a major nuclear accident, the disposal of radioactive wastes, and the production of nuclear weapons from byproducts of nuclear-powered facilities. Each of these issues is important to the public, however, from the viewpoint of effects on construction, only the first three are considered in this report (12:215).

Reactor safety is assured in the United States through a concept known as "defense-in depth." Nuclear power plants are designed, built, and operated under this concept. The regulations are also set-up to enforce the defense-in depth concept (3:316).

This concept has three key elements. First is the philosophy that the designer contemplates all accidents that he or she thinks have a significant probability of occurring, and designs against them. This includes intrinsically safe designs and engineered systems. Intrinsically safe means that the fundamental laws of physics are used for protection against accidents rather than human intervention. Second, the assumption is made that despite all good efforts in design, accidents will happen anyway, therefore redundancy must be built into the design. The third element is reactor design and siting to mitigate the consequences of accidents if the first two elements fail. Examples of this are: use of containment buildings to prevent release of radioactive material into the environment in the case of an accident, use of remote sites, and the filtering of airborne releases to reduce their magnitude (3:317).

One of the key design features of reactors in the United States is multiple barriers against the release of radioactive materials from the fuel. There are four barriers between the fission products in the fuel and the environment. First, the fuel is held together in a matrix

of ceramic-like material that basically immobilizes the fission products. Second, the fuel cladding retains any fission products that migrate from this fuel matrix. Third, the reactor primary vessel keeps fission products that escape the fuel cladding from leaving the reactor. Last is a containment building that encloses the entire reactor and the primary and secondary coolant systems. The effectiveness of each of these barriers is a major element in safe reactor design and operation (3:317).

Three other important areas must also be considered when designing a safe reactor. First is the ability to shut down the chain reaction and keep it shut down, this is known as the "scram" mechanism. The second area is maintaining structural integrity of the fuel, the primary coolant system, the containment building, and other equipment. Seismic, hurricane, and internally-generated reactor forces must be considered to ensure structural integrity. Lastly, the need for residual heat removal after a reactor scram is absolutely critical (3:317).

Unlike fossil-fired plants, nuclear plants cannot fully extinguish the heat generated from the chain reaction. A large amount of fissionable material remains in the reactor core after a scram and this produces heat as it undergoes radioactive decay. This decay heat must be removed or the reactor core will rise in temperature to the point where fuel damage will occur and release more and more radioactivity. This decay heat is removed

through the use of a long range heat sink. The removal of decay heat is one of the most vital issues in recovering from any reactor accident (3:317).

The reliance on automatic features and human operators is also an inherent design feature in the United States. Reactor designers have recognized that many safety-related functions work best if they are automated. They have also realized that some human intervention is also essential for safety. This is because the complexity of possible accident sequences is far too great to be controlled totally by automation. In the long run, human judgment, with its versatility and analytical powers, produces safer operation (3:318).

The possibility and effects of a major nuclear accident is the second key safety issue affecting public concern. From the public's viewpoint, the issue here is whether or not nuclear power is worth the risks that are involved. The nuclear industry defines risk, as related to reactor safety, to be the product of consequences times their probability of occurring. The public generally thinks in terms of large risks, which means large consequences or large probabilities, or both. The safety record of the nuclear industry has shown that the most frequent accidents have small consequences, therefore, the public's perception of the risks of nuclear power have been exaggerated (3:325).

The public needs to understand that even large accidents in the majority of reactors operating in the United States today are not analogous to the explosion of a nuclear weapon. No explosion or release of neutrons occurs, buildings outside the reactor plant are not physically damaged, nor are any fires started. Any damage to property, ground, or water that occurs is due to radioactive contamination. The danger to humans is the inhalation or ingestion of radioactive substances or gases, or irradiation from substances released to the atmosphere or deposited on the ground (12:460).

In 1975, the Nuclear Regulatory Commission conducted a study on reactor safety risk assessment. The findings from this study were published in a report known in the industry as the Rasmussen Report or WASH-1400 (12:216). The report stated that the risks of a major accident occurring that would cause large numbers of casualties are extremely small. The study showed that the probability is so small that it is not normally within the range of risks that are considered (12:217).

The WASH-1400 report was criticized for several reasons. The two main reasons were: casualty figures for the most severe types of accidents were underestimated, and accident frequencies were overestimated. However, if both of these figures from the study are altered to make a more conservative estimate, the risk of reactor accidents still remains small enough when compared to other man-

caused events (i.e. airplane crashes, fires, explosions) that nuclear power is still an acceptable means of generating electricity for this country (12:217). The nuclear industry must develop a program for educating the public on the actual risks that are involved so that public opinion is not swayed by the emotionalism and misinformation that is prevalent in the opinions of the opponents of nuclear power.

Despite the public's perception, the nuclear power industry maintains a remarkable safety record. There have been no large releases of radioactivity, no core meltdowns, no radioactivity-induced prompt fatalities, and excellent control of routine emissions during almost three decades of commercial reactor operation. This impressive record indicates the efficiency of the nuclear program in the United States and the dedication of those people in the industry who are committed to making nuclear power a safe energy alternative (3:323).

The last area of safety that appears as a threat to the public is disposal of radioactive waste. The public is understandably apprehensive about the ability of institutions and the industry to manage or dispose of radioactive waste. The main concern is the possibility of the release of this radioactivity into the atmosphere after the waste is stored (6:57).

Radioactive material remains in fuel rods that are no longer economical to use. Most of these fission products

(i.e. strontium 90 and cesium 137) have half-lifes of about 30 years. However, others such as plutonium, have half-lifes of up to 1000 to 10,000 years. With 112 reactors operating, the amount of radioactive waste is growing fast (6:57).

High-level waste from power plants in the United States has accumulated to 17,000 tons in thirty years. The same number of coal-fired plants operating for thirty years, under the current emission standards, would produce over 1 billion cubic feet of ash, 100 million tons of sulfur dioxide, and 1 billion tons of carbon dioxide (8:23).

The amount of waste that currently exists would fill all of the available storage space in the United States. The government and the industry have made little progress in developing facilities for storing this waste. However, Congress, in 1988, selected Yucca Mountain in Nevada as the site for a permanent storage area. Unfortunately, the State of Nevada has fought the plan so fervently that if the site opens at all, it will not be until 2010 (6:57).

Most experts agree that the waste problem can be handled with relative ease. The spent fuel rods can be vitrified and buried in steel containers thousands of feet below the ground. Highly accurate predictions have been made when nuclear waste is involved. Even though the risks are no more than encountered in everyday life, no one can guarantee that a disposal site would remain intact

for this long, or that groundwater intrusion would not occur. The public wants an absolute guarantee that the waste will never escape from the containers. Until this guarantee is made, public fears will not be overcome. "There will be no nuclear renaissance until a waste-disposal program exists that passes some common sense test of public credibility and acceptability" (6:57).

From an environmental standpoint, nuclear energy is the cleanest source of electricity currently available for large-scale growth. Nuclear reactor plants do not emit sulfur oxides, nitrogen oxides, particulate matter, or "greenhouse" gases such as carbon dioxide. More stringent air pollution regulations that are being enacted have no negative impact on the cost of nuclear power. The continued use of nuclear power helps prevent large amounts of air pollution annually. It has been estimated that the use of nuclear power in 1989 alone reduced emissions of sulfur oxides by 5 million tons, nitrogen oxides by 2 million tons, and carbon dioxide by 128 million tons (1:17).

Another factor affecting the public's opinion of nuclear power is the staggering costs involved with construction. Unfortunately, one of the methods employed by utility companies to raise capital costs for construction is a rate increase. It is difficult for the common consumer to understand why he or she has experienced a medium term (3 to 5 year) rate increase to

pay for a nuclear power plant that may be completed in 15 to 20 years so rates will then go down.

Also of concern are the enormous amounts of money that have been sunk into nuclear power plants only to have the plant construction stopped or the plant abandoned after completion because of a licensing challenge. Some examples are: the Long Island Lighting Company of New York gave up on trying to obtain a license on its completed $5.5 billion Shoreham Nuclear Power Plant in 1989. The reason for abandonment was local authorities refused to approve the company's plans for evacuation in the event of a major accident. The State of New York plans to buy the plant for $1 and have it dismantled at a cost of $186 million. A regional utility company in Indiana stopped construction on a nuclear plant in 1984 after sinking $2.7 billion (6:56).

The financial brokerage firm, Merrill Lynch, has estimated that abandoned nuclear projects in the United States has cost utility stockholders $10 billion. "The first utility that announces plans to build a new nuclear reactor will see its stock dumped" says Leonard Hyman, Merrill Lynch's expert on electric utilities. Stockholders are still trying to recover from their first experience with losses. "There is no demand for new plants, because no one wants to spend the next 10 years in court or being picketed" states Hyman (6:57).

Nuclear power has been and probably will remain a controversial issue in the United States. Despite the polls that have shown that the majority of Americans think nuclear power is our most promising source of energy for the future, there exists a significant faction of strong opposition to it. These opponents of nuclear power will likely continue their efforts to persuade the public to abandon this source of energy. Nuclear power opponents are highly organized and maintain a well-established information network. The bulk of the information that is circulated is highly partisan, but contains just enough facts to keep the opposition much better informed about nuclear power than the general public (12:260).

The fight for survival of the nuclear industry in the United States is mostly a contest among groups in our society, and not the public as a whole. The leadership of the anti-nuclear movement is clearly in the hands of environmental organizations. The proponents of nuclear power are led by industries and professional associations within the nuclear power field. Each group is trying to gain public support (12:260).

The scientific community plays a critical role in the nuclear power debate for two reasons. First, scientists are found on both sides of the issue. Second, both sides of the issue are eager to get scientific support for their viewpoint. More importantly, scientists are held in high public esteem in regard to nuclear power, much more than

either of the other two groups. One factor affecting public opinion is that scientists themselves are not decided on the need for nuclear power in respect to the risks involved (12:261).

How has the public's perception of nuclear power affected the construction of nuclear power plants? As mentioned in Chapter 2, the current licensing procedures allow for the public to intervene during both of the steps required in the two step process. The law requires that a public hearing be held prior to the issuance of the construction permit and also prior to the issuance of the operating license. "Interventions have been used to build up opposition to nuclear power, and in some cases, have forced postponement or cancellation of nuclear plants, either by generating resistance in the region affected, or by delays that bring the economics of the plant into question" (12:278)

The most effective method of combatting the opponents of nuclear power is through education. If the current administration and the nuclear power industry want to experience additional growth, they must develop together a comprehensive plan of educating the public on:

1. The amazingly low risks of nuclear power when compared to the risks of everyday life.
2. The remarkable safety record of the industry.
3. The technology that exists for the proper and safe disposal of radioactive waste and the real risks associated with this technology.

4. Why construction costs have skyrocketed, and the long term consequences on electricity rates if nuclear power is not allowed to reach its full potential.

5. The positive effects on the environment if nuclear power is allowed to grow.

These points must be made totally clear to the public if nuclear power is to survive. Also, the fifteen years of misinformation publicized by the opposition must be dispelled in order for the public to really understand what it needs to know to make intelligent decisions regarding nuclear power.

CHAPTER 5

QUALITY ASSURANCE AND QUALITY CONTROL

"Man has been interested in quality construction for many years" (4:349). However, nuclear power plants have had much more emphasis on quality in construction than on typical construction projects. This added emphasis is necessary because of the fuel that is used in a nuclear power plant. Since radioactive fuel is used, extreme care must be taken to ensure that accidents are prevented from occurring during plant operation. One method of providing the necessary care is to ensure that quality materials and sound construction practices are used during the construction of the plant (4:369).

Because of the tremendous potential for damage and the number of lives that may be affected by an accident, the Federal government has established certain standards to ensure that nuclear power plants are constructed with the necessary quality to provide for safe operation. This level of government involvement is not found on typical construction projects. For this reason, nuclear power plant construction has a unique position in the construction industry (4:350).

The principal focus of this chapter will be on quality assurance (QA) and quality control (QC), and the

effects of these two areas on the industry. A review of the NRC's role and the requirements of the federal regulations governing nuclear power plant quality assurance is necessary in order to understand how the QA/QC program affects the overall outcome of construction. Also, the owner's involvement in QA and how QA is integrated into projects is discussed. Finally, problems with the current QA regulations are reviewed to emphasize that improvements in this area are also necessary if the industry is to experience additional growth.

Title 10, Part 50 of the Code of Federal Regulations, which governs the construction and operation of commercial nuclear power plants, defines quality assurance and quality control as follows:

> Quality Assurance--All those planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service.
>
> Quality Control--Those quality assurance actions related to the physical characteristic of material, structure, component, or system which provide a means to control the quality of the material, structure, component, or system to predetermined requirements (17:621).

The primary purpose of the quality assurance program in nuclear power plant construction is to provide assurance that the health and safety of the public will not be endangered during the operation of the plant. QA affects every aspect of the engineering, construction, and operation of the plant. It is based on a logical, step by step method of assuring that the design meets the plant

criteria and that the intent of the designer is met during construction. To be effective, the QA program should be looked at as a management tool to assist in achieving objectives and not only as a means of satisfying the requirements of the NRC (10:474).

In 1969, the Atomic Energy Commission (now the Nuclear Regulatory Commission) published Appendix B to Title 10, Part 50 of the Code of Federal Regulations. Appendix B is entitled, "Quality Assurance Criteria for Nuclear Power Plants." Appendix B has become the foundation for all of the QA requirements that must be strictly followed during the design, construction, and operation of nuclear plants. This document delineates the requirements and responsibilities through eighteen criteria. Each of these must be addressed in the formal QA program of each party involved in the construction (4:350). The eighteen criteria are:

1. Organization
2. Quality Assurance Program
3. Design Control
4. Procurement Document Control
5. Instructions, Procedures, and Drawings
6. Document Control
7. Control of Purchased Material, Equipment, and Services
8. Identification and Control of Materials, Parts, and Components
9. Control of Special Processes
10. Inspection
11. Test Control
12. Control of Measuring and Test Equipment
13. Handling, Storage, and Shipping
14. Inspection, Test, and Operating Status
15. Nonconforming Materials, Parts, and Components
16. Corrective Action
17. Quality Assurance Records
18. Audits (17:324)

As illustrated by the number and type of areas covered, the QA program for a nuclear power plant is quite extensive and comprehensive. Consequently, the NRC's requirements in QA are very time-consuming and costly.

Appendix B of 10 CFR 50 places the responsibility for the establishment and execution of the total QA program on the utility or owner. This function may be delegated to contractors, agents, or consultants, but doing so does not relieve the utility of any of its responsibilities under the law. Before this requirement became effective in 1969, most utilities were using turnkey contracts for the design and construction of nuclear power plants. However, since the owner was made responsible for the QA program, turnkey contracting became obsolete in the nuclear power industry. Owners have been forced to take a more active role in the engineering, procurement, and construction phases of the project (4:354).

A wide variety of owner involvement in QA programs has existed on nuclear projects in the United States. For example, large public utilities, such as the Tennessee Valley Authority (TVA), have conducted all the engineering, procurement, and construction on their projects. On the other extreme, small utilities that have built only one nuclear power plant have delegated all engineering and construction functions, including most of the QA and QC functions, to an architect/engineering firm or construction management firm. On a majority of

projects the utilities have delegated most of the site-related quality assurance functions to a contractor and the utilities have performed audit functions on the contractor's QA efforts (4:355).

The most common set-up for the overall QA organization has been one where the site constructors conducted first and second level QA/QC functions and the utility maintained only a small staff at the project site. This small staff was used for conducting the audits. The utility would also have a small QA staff at the home office to audit the QA programs of the various vendors and material suppliers on the project (4:355).

Because of Appendix B's requirement that owners be responsible for the overall quality of the project, many utilities felt that minimum involvement (i.e. audit functions only) was not sufficient. The trend has been for the utility to retain more and more of the quality-related inspection, surveillance, and auditing work. This trend was exemplified in the construction of Florida Power and Light Company's (FPL) St. Lucie Unit No. 2 Nuclear Power Plant in Stuart, Florida. On this project, FPL maintained direct control and responsibility for the site QA and QC (16:11).

Florida Power and Light felt that having a separate QA organization for surveillance only was a duplication of effort that wasted valuable resources of manpower, time, and money. FPL performed all site QA and QC activities on

this project and delegated offsite QC functions, namely vendor surveillance and design control, to its design engineer/contractor. Management positions were staffed by FPL employees, while a service contractor provided most of the inspectors (16:13).

Another area of QA that has had an effect on nuclear power plant construction is the requirement that: "persons and organizations performing quality assurance functions shall report to a management level such that this required authority and organization freedom, including sufficient independence from cost and schedule when opposed to safety considerations are provided" (17:621).

This requirement has affected the project organization and the overall corporate organization of utilities. Not only has it affected utilities, it has also affected contractors and designers in the nuclear power industry, since many QA functions have been delegated to their level. The key words in the requirement are "sufficient independence." Experienced utilities, suppliers, and engineers have found that sufficient independence could only be achieved by giving the QA manager a position equal in authority to the project manager or the departmental heads of engineering and construction (4:354).

Probably the greatest effect on the industry caused by the QA program has been the requirement that there be

written procedures. The QA Program criterion of Appendix B states:

> The applicant shall establish at the earliest practicable time, consistent with the schedule for accomplishing the activities, a quality assurance program which complies with the requirements of this appendix. This program shall be documented by written policies, procedures, or instructions, and shall be carried out throughout the plant life in accordance with those policies, procedures, or instructions (17:621).

This requirement is significantly different from the typical construction project. Most construction projects do not require written procedures and do not always adhere strictly to the specifications. However, for nuclear construction written procedures are a must and strict compliance with the specifications is an absolute requirement according to this Federal statute (4:356).

Because of the volume and complexity of operations involved with a nuclear power plant, the requirement for written procedures does have some merit. The QA program must be followed throughout the life of the project. In order to ensure that this is done, project personnel must be given direct and clear guidance. Construction procedures are written to ensure that each similar task is performed the same way by each worker on the project. The written procedures also provide assurance that each operation is done in compliance with the project specifications. The QC inspectors and QA personnel receive their guidance through the written QA and QC procedures. These procedures specify: the job that must

be done, when it will be done, step-by-step details on how the job will be done, the equipment required to do the job, and the documentation required (4:357).

Because of the large number of activities on a nuclear power plant, problems have arisen when written procedures are too detailed. If the writing of procedures is not done carefully and methodically the number of procedures can rise to unmanageable levels. On one two-unit nuclear power plant there were 108 construction procedures and 43 QA/QC procedures (4:357).

Not only must the number of procedures be controlled, but how the procedures are written must also be managed. Very often the procedures are difficult for construction personnel to follow or the procedures do not accomplish their intended purpose. This causes extensive revisions, which are costly and time consuming, both from an administrative and a construction operations standpoint. On the two-unit plant mentioned in the previous paragraph, there were 367 construction procedure revisions and 119 QA/QC procedure revisions. Revisions are often necessary to update procedures, but how many revisions are necessary because of procedures that were not well planned and prepared the first time (4:358)?

Each revision causes a logistics problem and generates a large volume of paper. Each person who has a copy of the original procedure must obtain an up to date copy with the latest revision. Usually, a field change is

approved before the official revision is published, so everyone must also receive a copy of the field change. Considering the large number of personnel involved with the written procedures it can be easily seen that procedures and their revisions can become a costly and time consuming effort (4:358).

Another requirement of the QA Program criteria of Appendix B is that the program must be able to provide "verifiable objective evidence of quality performance" (17:622). One aspect of this evidence is written procedures. The other aspect is documentation of what has transpired. This is done through field reports, testing, and photographs. While there is a certain amount of documentation that is necessary to ensure that the QA program is working, documentation alone cannot ensure quality.

The main focus of the entire QA program should be producing a quality product, the paperwork provides the assurance that quality was achieved. A survey of management personnel directly responsible for QA in the nuclear industry indicated that QA programs were too paper oriented. Many of those surveyed stated that "industry overreaction to regulatory requirements and resultant overspecification of documentation requirements" was a leading factor in unnecessary paper production. This overreaction is probably due to the industry's desires to ensure regulatory requirements are met. Quite frequently,

specifications were made more stringent than were required to meet existing regulations (4:359).

The problem with overdocumentation can be illustrated with a few examples. On one project it was estimated that over 500,000 documents were generated from field activities alone! On another project, the QC procedure for tags and forms was a 66 page document which contained 53 different forms. One site that was studied revealed that there were nine different forms that had to be completed prior to each concrete placement (4:359). It is easy to see how over half a million pages can be generated when forms and records are required for each weld, concrete placement, and numerous other activities. It is also easy to determine how the administrative and overhead effort required to generate, distribute, complete, and maintain these documents can inflate the price of the project.

The requirements of Appendix B are the subject of much controversy and interpretation within the industry. The differences in interpretation have been dramatic. Utilities, suppliers, designers, contractors, and the regulatory agencies have all had varying viewpoints on how to interpret the requirements. Although Appendix B set forth general requirements for QA programs, it was apparent from the early stages of its use that clarification of acceptable interpretations and specific guidelines was needed. Much of this was accomplished

through the various codes and standards of the national societies, such as the American Concrete Institute (ACI) and American National Standards Institute (ANSI) (4:351).

However, there are still many areas where the industry failed to agree on acceptable interpretations. Since the industry could not agree, the NRC published what it felt were acceptable requirements which would guarantee that quality was obtained. These were published in the form of NRC regulatory guides (4:352).

A regulatory guide is a description of an acceptable method of implementing a specific NRC regulation. These guides are developed with information and assistance from industry. Within one category (related to power reactors) there have been over 100 regulatory guides published with more than 60 others in various stages of development. The continuous revisions and clarifications of these guides are the source of much frustration in the industry (4:352).

It is these revisions and clarifications that have caused the unstable regulatory climate that has existed for the past decade which has had a direct negative effect on the industry. It has been extremely difficult for utilities, designers, and contractors to plan, design, and construct nuclear power plants to a specific timetable and budget when the regulations are constantly changing.

CHAPTER 6

CONSTRUCTION MANAGEMENT

With construction costs escalating at a rapid rate, one of the major problems facing construction managers on nuclear power plants is how to obtain more effective and efficient use of resources. Time management is a critical area of planning that involves a major resource in construction. It is especially critical in nuclear power plant construction because of their size and complexity (2:1).

During the mid-1980's, a study of nuclear power plants in the United States indicated that poor time management was a significant problem in their construction. Many construction companies possess the tools and techniques available to manage time, however, this possession is no guarantee that a project will be completed successfully. A basic framework for time management should be established and utilized by the entire construction organization. It should be comprehensive, yet clear enough so that external groups can understand how it works. The four processes that make up this basic framework are: planning, estimating, scheduling, and control (2:2).

Effective planning is essential for the successful completion of nuclear plants. Historically, the most successful projects have had quality planning from their inception. Quality planning is more than just generating paperwork by some group in management. Engineering, operations, construction, maintenance, staff departments (i.e. QC, radiological controls, purchasing), suppliers, subcontractors and top management must all participate in order for the plan to be realistic and effective (2:2).

The planning process should consist of developing an outline on: what has to be done, when it has to be done, how it will be done, and who will do it. This is common to planning any endeavor. However, for a nuclear power plant some other conditions must also be met. First, the planning group must know and understand the strategy to be followed--what methods and procedures will be used, the lines of authority and responsibility of the many organizations involved in the project, and what accuracy the planning process is expected to achieve. Secondly, the involvement of all project members is required for an effective plan that will be accepted and committed to by everyone. Third, major milestones must be established, with each milestone linked to a specific deliverable item or result. Last, a good work breakdown structure must be developed. Because of the size and complexity of a nuclear power plant, the requirements of information

integration and communication are much greater than those normally encountered on other construction projects (2:2).

If the planning process is done correctly, the entire organization should understand it and the individual project groups will be committed to making the plan work. The next phase in time management, estimating, will be much easier because: an overall strategy for the project has been developed, milestones and results have been identified, and the work breakdown structure has been established.

Even with all of the sophisticated techniques available in the construction industry for estimating, this phase of planning for a nuclear plant can only be accomplished with a limited degree of accuracy. The major limitations on estimating accurately are the many uncertainties associated with regulations, resources, and working conditions. Even though it is often difficult to estimate activity durations with assured accuracy, it is not totally impossible. Using the WBS, historical data, and information from the group actually performing the work, a reasonably accurate estimate can be made (2:3).

The estimators must determine the resources required to accomplish planned activities along with the constraints and limitations that may affect the duration of the activity. Interfaces and interference between resources should be identified, and the impact of each determined. When estimating activity durations on a

nuclear power plant, the constraints of: access, regulatory procedures, security, training, and radiation exposure limits must all be considered. All of these areas will limit productivity and the availability of resources. This in turn will lengthen the activity durations (2:3).

With the resources and constraints identified, the project activities can be analyzed to determine duration. As many alternatives as possible should be evaluated as to their feasibility. Each feasible alternative should be carefully reviewed to obtain a duration. After realistic activity durations have been established, the next phase of time management, scheduling, becomes somewhat easier (2:3).

Effective scheduling of a nuclear power plant requires a degree of construction management skills above just being able to produce a CPM schedule. It requires communication of information processing skills in order to define the schedule objectives and the administrative support necessary to use the schedule for it's intended purpose--the control of project time. Effective scheduling also requires the ability to acquire the necessary resources and the commitment of top management to the schedule (2:3).

The scheduling process consists of recognizing the time and resource restraints that will influence the execution of the project plan. More sophisticated project

scheduling functions involve: determining interdependency between tasks, placing each task in sequence based on these interdependencies, placing the sequence of tasks in real time (on a calendar), analysis of the schedule for constraints and alternatives, and finalizing the schedule (7).

After completing the above activities the schedule should be written in a format which can be communicated to the project members for their use in monitoring progress. Before the schedule is officially adopted and issued, it should be reviewed by everyone involved in the project. Any questions and problems that arise during this review should be discussed and resolved (2:4).

As with any construction project, the schedule is an extremely useful tool in controlling time and costs. However, the construction management team should realize that planning, estimating, and scheduling can easily get out of control on a nuclear project. These processes typically become an end to themselves and prevent the efficient use they were intended to provide.

For the schedule to remain effective it must be easily adaptable to the changes in scope, resources, and regulations that are inevitable on a nuclear project. To achieve adaptability, the schedule should be prepared in a format that can accommodate changes through a formal revision process. Project personnel must collectively understand and believe in the schedule if the project is

to be a success. "It is a serious mistake to believe that the performance of the project can be controlled simply by monitoring the schedule" (2:4).

Monitoring is an effective means for identifying out-of-control situations. However, the project must be controlled in regards to the schedule in order to be successful. The control process involves: collecting data, identifying variances and analyzing their impact, reporting variances, evaluating the alternatives for corrective action, and selecting and implementing the right alternative (2:5).

In nuclear power plant construction for the control process to work, other factors must be taken into consideration. A formal and clearly defined control organization is an absolute necessity. With clearly defined roles, tasks, and responsibilities, role conflicts between the players are minimized and confusion over accountability is reduced. The management tools used for defining responsibilities are: work tasks and performance standards, task matrices, organizational charters, organizational input/output statements, personnel rosters, and regularly scheduled meetings (2:5).

The most important job of the control organization is to communicate the real project status to the project players, top management, and other involved parties (i.e.major vendors, the NRC). An effective reporting system should be established to provide project status at

the proper level of detail and frequency. The reports should be provided to those people in the organization who have the ability and authority to make decisions. For this group, controlling the project performance means helping project personnel, collectively, to stay on top of the work and identify problems while they are small, or before they occur. Doing this provides the control group with more assistance and support in problem solving throughout the life of the project, which will inevitably lead to project success (2:5).

The control process, if done correctly, involves the control and performance organizations. These two groups working together provide insight into the many intricacies of a nuclear power plant project and the methods that can be used to manage time and reduce costs. This fosters teamwork and a total commitment toward reaching each critical project milestone which leads to overall project success.

The control process involves four main areas: schedule, cost, material, and quality. Each of these areas is interrelated and deficiencies in one area usually result in problems with the other areas. Previously this chapter discussed the organizational format and functions of scheduling and control organizations. The next section of this chapter will review the types of project schedules, cost estimates, and material controls typically

utilized for nuclear power plant construction. Quality control is discussed in a separate chapter of this report.

The schedule control system is comprised of several different types of schedules. The Main Event Time Scaled Schedule is the initial and principal schedule from which all the other project schedules evolve. It is manually prepared and usually contains forty to one hundred key events. It does not contain nonevent-related contingencies such as strikes, unusually severe weather, and design changes. The Official Project Schedule is a detailed computerized schedule that incorporates all essential engineering, procurement, construction, and testing activities. It is only "official" until it is formally superseded by another Official Project Schedule (10:472).

The Simulation Schedule is an interim step between a proposed change in the existing Official Project Schedule and the production of a new official schedule. It is a series of integrative computer printouts that updates the official schedule. The Schedule Status Reports are physically identical to an Official Project Schedule, but reflect the current status of the project and indicate the deviations from the official schedule (10:473).

The project managers and planning and scheduling engineers implement the Official Project Schedule. The planning and scheduling engineers update the computer on a periodic basis to reflect the current status of the

project and issue the Schedule Status Report. This report indicates the deviations from the official schedule that will occur if corrective steps are not made. When project management does not think that the deviations can be corrected by logic changes, additional manpower, or improved productivity, the planning and scheduling engineers do simulation runs to develop a new simulated schedule that is submitted for approval to project management. When approved, a new Official Project Schedule is issued and the cycle is repeated throughout the life of the project (10:473).

Cost control, to be effective, must be based on accurate estimates. For nuclear power plant construction several different types of estimates are used from inception to completion of the project. They maybe called different names but are generally known as: order of magnitude estimates, preliminary detailed estimates, and definitive estimates (5).

Order of magnitude estimates are prepared during the early stages of the project and updated regularly. These estimates are based on historical data and have a low degree of accuracy. They are applied during the conceptual engineering and design phase. Preliminary detailed estimates are issued shortly after the preliminary safety analysis report (PSAR) is submitted to the NRC. These estimates are established for the purpose of monitoring the full range of project costs at all

levels of detail. These estimates are updated periodically, usually every six months. The definitive estimate is prepared upon awarding the construction permit. It provides the greatest degree of accuracy at the time it is prepared. It is based on quotations for major pieces of equipment, the construction materials, and a detailed labor survey (10:472).

A computerized system is used to disseminate cost estimates and to incorporate cost control feedback into the system. The computer develops and generates different reports for the use of corporate management, project management, and field personnel (10:472).

Project material control is also essential in tracking and reducing cost overruns. Computer programming is utilized to assign the direct responsibility for on-time procurement to an individual in the responsible organization. Each significant equipment or material item is identified and tracked by computer from procurement to final delivery.

The computer is also used to develop several reports which assist management and field personnel in material control. The Master Listing contains the entire material file and provides: system code, description, responsible individual, vendor, purchase order number, quantity info, order date, and special codes. The Warehousing Report lists all ordered items that have not been received. The

Expediting Report itemizes those items that are overdue or due to be shipped within 90 days (10:473).

This chapter has reviewed a model process for managing a nuclear power plant construction project. Also discussed were the typical reports being used and their implementation in regard to schedule, cost, and material control. The last portion of this chapter will review what construction managers in the nuclear industry think of planning, schedule performance, and cost control. The survey, conducted in conjunction with a MBA thesis project at New York University Graduate School of Business Administration, was taken in 1978, at a time when nuclear power plant construction was almost at it's peak in the United States. The results are merely used in this report to emphasize and provide insight into those areas pertaining to construction management that need improving. Two hundred thirty-four individuals from public utilities, architect/engineer firms, and construction firms were surveyed (15:491).

A majority of those surveyed indicated that construction planning is in need of the most improvement. The second area most frequently mentioned as needing improvement was the direction of construction operations, and the third was construction performance review and evaluation (15:492).

The planning task was further broken down and rated by level of importance, and current performance (strong or

weak). The following areas of planning were rated both high in importance and weak in performance:

1. Input to licensing and engineering activities concerning commitment to practicality and design feasibility.

2. Plant construction activity planning and scheduling.

3. Construction methods planning,including introduction of innovative techniques.

4. Construction organization and administrative planning.

It is interesting to note that Item 1 received this rating from an exceptionally high number of respondents (46%) (15:494).

The survey also attempted to identify other areas of construction planning that if emphasized would improve overall performance. Among these areas were: material planning, expansion of construction performance planning into more diverse areas, manpower and labor resource planning, estimating and cost control, and preparation of start-up activities (15:495).

Field direction of operations was considered by many of those surveyed as the second most important management category regarding nuclear projects. Despite extensive management efforts in planning, review, and evaluation, overall project success is greatly dependent upon direction of construction operations. The top four areas rated in this category were:

1. Obtaining timely engineering information.

2. Completion of construction activities on schedule.

3. Maintaining unit performance per estimate (project cost performance).

4. Obtaining materials and equipment.

(15:496).

The survey also asked the respondents to list additional management tasks where current industry performance is weak. The following items were at the top of the list:

1. Day-to-day planning and scheduling of construction activities.

2. Maintenance of quality control requirements and integration of quality control activities with construction.

3. Construction leadership and supervision.

4. Communication and coordination with other departments.

When asked how to improve performance in the area of construction operations the following responses were given by a majority of the construction managers surveyed: more detailed planning, greater development of the engineering/construction interface, and staffing by more experienced personnel (15:498).

Regarding construction performance review and evaluation, total cost to completion forecasting was judged weak by over half of the respondents. Also rated as weak were: overall construction completion status and specific activity completion status. Most of the responses indicated that review and evaluation tasks were

performed by construction supervisors, rather than an independent group (15:498).

The results of the survey suggested that improved performance was needed. Improved performance could be achieved by correcting problems mostly on an individual project level. Greater resources should be applied to planning tasks on future nuclear projects. This requires a larger and more experienced planning staff. Construction planners should concentrate on review of project licensing commitments and construction input to project engineering and design. The plans should include greater flexibility for response to the inevitable change experienced during nuclear construction (15:499).

Direction of construction operations could be improved by making every effort to free supervision of extraneous tasks. This allows for concentration of the construction supervisors on those activities essential for efficient work performance. Coordination and communication should be emphasized. Because of the pressures and stresses experienced by managers on nuclear construction sites it is important that training and professional development of personnel be given top consideration of management. Job assignments should be made in consideration of professional development (15:500).

Although this survey was conducted in 1978 the points it raised and the areas identified for improvement are

certainly relevant today. Many people in the nuclear industry have placed the blame on government regulations as being the sole cause of the decline in the nuclear power plant construction industry in the United States. As this survey indicated the construction industry has much room for improvement in it's management of nuclear projects. It is interesting to note that during the rapid escalation of costs and extreme schedule overruns that occurred during the late 1970's and through the 1980's the construction industry and utility companies were blaming the NRC and it's regulatory process. The NRC on the other hand, was claiming that poor management and declining productivity of construction labor was causing the cost overruns and schedule extensions. Since that time the NRC has recognized that the licensing process is partially to blame for the problems. The construction industry has realized that there are many areas of improvement, especially in management that can reduce cost and improve schedule performance.

This chapter has identified a model process for managing the construction of a nuclear power plant, provided a review of the different methods used by the industry to track and control costs, schedules, and materials. Also, specific areas of improvement identified by construction managers were reviewed.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

CONCLUSION

In an attempt to gain insight on the problems with the nuclear power industry I conducted an interview with Dr. Jack O'hanian, Assistant Dean, College of Engineering, University of Florida. Dr. O'hanian is the immediate Past-President of the American Nuclear Society. The American Nuclear Society is a non-profit organization of engineers, scientists, and educators dedicated to the advancement of engineering and science related to nuclear science and technology and the integration of the scientific and management disciplines of nuclear science (14).

As indicated by his comments, Dr. O'hanian's thoughts reflect many of the same ideas that were looked at in this study. The interview was conducted on Jun 26, 1991. The following is a review of Dr. O'hanian's comments:

> Two issues have contributed significantly to the decline of nuclear power in this country. The first issue is economics. American utilities were overly optimistic in their projections of electricity demand for the '70's and '80's. Nuclear power plants were ordered in the '60's and '70's based on these projections. The oil embargo of 1973 caused conservation efforts to take place and electrical demand decreased to the point where nuclear power was not as cost effective as originally anticipated.

The second issue is the licensing process, which is interrelated to public opinion. The French, who generate 75% of their electricity with nuclear power (and will probably reach 80% by 1995) have no problems with licensing. They have one standardized reactor design and one utility company. They also have no other alternative fuel choices. In the United States, we have over 3000 utility companies, 60 of which are in the nuclear business and many different designs for our reactors. The public is not convinced that nuclear power is safe and is not willing to give up its chance at a second public hearing, even though Congress is contemplating legislation which would require only one hearing and one license. Since the public does not appear to be willing to forego the second hearing, it is doubtful that Congress will either. There is likely to remain a "confirmatory hearing" at the end of construction to ensure the plant has been built to specifications. The people are not in favor of nuclear power. Everyone thinks it's a good idea until plans are announced to put a plant in their own backyard.

On standardization, the most likely choice will be the advanced light water reactor. The designs are being finalized now and one (nuclear plant) could probably start construction in two to three years. The gas-cooled reactors (MHTGR) are a good design, but no one has much experience with them. Therefore, no one wants to take the financial risk of experimenting to see how they work. Two gas-cooled plants have been built in the United States. One has never operated properly and has had its license removed by the NRC.

I have had some experience with actual construction of nuclear plants. My observation is that much depends on the utility and how they tackle nuclear construction. A crucial factor is to what extent the owner controls the construction. A good example is the St. Lucie Power Plant owned by Florida Power and Light. The owner was almost totally involved in every phase of the construction and the plant was built in about six years. In my opinion constructing a nuclear power plant is like any other project, if the right people are put on the job and the job is managed properly, there will be few problems and the plant will be built as intended.

> Have you ever heard of Admiral Rickover? (My answer to this question was a definite yes. I explained to Dr. O'hanian that I had been interviewed by Admiral Rickover in 1981, prior to my entry into the Navy's submarine training program.) He was always after the best in the Navy's nuclear power program. His attitude of excellence and care is one that we need to emulate. Our motto has to be "do it right the first time."
>
> The accidents at Three Mile Island and Chernobyl made a big difference. After Three Mile Island, the nuclear industry and the NRC realized that changes were required in many areas of nuclear power if the industry was to survive. For the most part these corrections have been made and the industry is in much better shape today. Chernobyl scared everyone. The public does not understand what type of plant Chernobyl was and what actually happened there. That type of accident could not possibly occur in the United States because we operate a totally different system. Chernobyl did cause an international review of nuclear plants and their operations with emphasis on the Soviet Union and other Eastern bloc countries.
>
> A lot of the problems with the industry depend on attitude. Everyone, by everyone, I mean all of us in the nuclear industry worldwide have realized that there is no such thing as a local accident. An accident at any nuclear plant in the world affects everyone. We are all in this together (14).

Nuclear power plant construction in the United States has declined rapidly during the past fifteen years. There are many reasons for this decline, but the critical ones are: the current two-step licensing process that requires public hearings at each phase of licensing, unstable regulatory conditions that prevent proper control of construction costs and schedules, the lack of a standardized design or a group of standardized designs, the public's negative opinion of nuclear power, and the

failure of the construction industry to adequately prepare itself to deal with the complexities of building nuclear power plants.

By the year 2030, the demand for electricity in the United States is expected to increase 300% over the country's current generating capacity (6:57). Because of recent problems with oil exporting countries in the Middle East and environmental concerns fossil-fuel plants are no longer the optimum choice for utility companies. Nuclear power is once again emerging as an alternative for producing clean, efficient, and cheap electricity in this country. However, to remain consistent as a primary source of energy, nuclear power must overcome the problems which has caused its decline during the past fifteen years.

RECOMMENDATIONS

For nuclear power to again become a viable energy source those involved in the industry must make a concerted effort to educate the public on its many virtues. Environmental concerns, economics, and the industry's safety record are the key issues that should be highlighted to emphasize to the public the advantages of nuclear power. Once the public is again in favor of nuclear power, then the industry must do everything possible to ensure that no significant accidents occur that would negatively sway public opinion.

Congress generally follows public opinion in enacting legislation or reforming legislation. After Congress is convinced that the public wants nuclear power, the licensing process should be changed through new or revised legislation. The licensing procedure must be streamlined so that utility companies and construction managers can reasonably estimate the time and costs involved with designing and construction nuclear power plants. A one-step procedure with the license issued prior to construction and the approval of the plant tied directly to the issuance of this license is crucial to removing the risks involved from not accurately estimating the cost and duration of plant construction.

Also related to government control and reform are the NRC's requirements. The regulatory guidelines must be revised to allow for construction to be completed without constant design changes. These constant design changes create another unnecessary risk that the owner and contractor should not have to manage. Also, the public should not be forced into paying for these risks in the form of increased electrical rates.

Finally, the government and industry should strive toward developing a standardized design or a group of standardized designs that can be built within a certain range of the cost and schedule estimates. The experience factor related to building the same plant on a repetitive basis will ultimately cause the construction costs and

durations to decrease. This will also improve operability, safety, and maintainability for the entire industry. Another advantage of standardized design is improvement in the ability of the NRC to more quickly review the design and issue licenses faster.

The recommendations made in this report have been extracted from my study of the problems that have confronted nuclear power for the past two decades. The resolution of the problems facing the nuclear power industry will require an extremely coordinated and concerted effort from all the parties involved--the public, the industry, government regulatory agencies, the Administration, Congress, and the environmentalists. The effort to revive the nuclear power construction industry in the United States will certainly not be an easy one.

I recommend that future research be conducted on the effects of public opinion on the industry, especially in regard to construction cost and schedule overruns resulting from public intervention in the licensing process. Also, the current legislative reform efforts in Congress should be closely followed to determine if major revisions will be made to the regulations that will favor standardization and lessen financial risks for owners and contractors.

GLOSSARY

ADVANCED LIGHT WATER REACTOR: A new reactor design that provides for improvement over the current LWRs that are operating. Light water describes the type of primary coolant that is used to remove the heat of fission from the reactor core.

APPENDIX B: An appendix to Title 10, Part 50 of the United States Code of Federal Regulations that defines the quality assurance and quality control requirements for commercial nuclear power plants.

CHERNOBYL: Site of a major nuclear accident that occurred in April 1986, in the Soviet Union.

CONTAINMENT BUILDING: Building that is constructed around the reactor and its major systems that is a key design feature in preventing release of radioactive material into the atmosphere.

CORE MELTDOWN: Term used to describe an event that occurs when decay heat is not removed fast enough from the reactor core, causing the fission process to increase at an accelerated rate, producing enough heat to melt the reactor core.

DECAY HEAT: Additional heat that is generated from the fission process after the reactor has been shutdown.

DEFENSE-IN-DEPTH: Design concept utilized in the United States to provide for maximum safety in the operation of nuclear power plants.

GREENHOUSE GASES: Gases released into the atmosphere that contribute to the greenhouse effect.

MODULAR HIGH-TEMPERATURE GAS COOLED REACTOR: Reactor design that uses helium gas as a heat transport mechanism. Currently being studied as a standardization option.

NUCLEAR FUEL CYCLE: Term used by the industry to describe the overall process of nuclear fuel, from the extraction of the uranium ore to the disposal of radioactive waste.

NUCLEAR REGULATORY COMMISSION: Independent agency of the United States Department of Energy that provides oversight

on all facets of commercial nuclear power, especially design, construction, and operation.

RADIOACTIVITY-INDUCED PROMPT FATALITIES: Death caused by instantaneous exposure to radiation, as opposed to death caused by long term exposure to radiation.

RASMUSSEN REPORT (WASH-1400): Report from a study commissioned by the Nuclear Regulatory Agency in 1975 to study the risks involved with nuclear accidents.

STANDARDIZATION: Concept where a single design or a small group of designs is utilized to construct all the nuclear power plants vice having each plant custom-designed and built.

10 CFR 50: Title 10, Part 50 of the United States Code of Federal Regulations that regulates all facets of commercial nuclear power.

THREE MILE ISLAND: Site of a nuclear accident that occurred in March 1979, in Pennsylvania.

TWO-STEP LICENSING: Current licensing procedure used for nuclear power plants. It requires two separate licensing steps, one prior to starting construction, and the second prior to commencing operation of the plant.

VITRIFICATION: Process that uses extremely high temperatures to convert radioactive wastes into a glassy-like substance in order to reduce its volume and provide for ease of storage.

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